GRASSROOTS JOURNALS

Grassroots Journal of Natural Resources, Vol.7 No.3 (December 2024)
ISSN: 2581-6853 | CODEN: GJNRA9 | Published by The Grassroots Institute
Website: https://grassrootsjournals.org/gjnr | Main Indexing: Scopus and WoS

ISSN 2581-6853 | 7(3) Dec 2024

M – 00476 | Review & Analytical Article

The Role of the Circular Economy in Advancing Environmentally Sustainable Industrial Production

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How to cite this paper: Gorokhova, T., Kozlova, A., Laguta, Y., Skrashchuk, L. and Kaminskyi, S. (2024). The Role of the Circular Economy in Advancing Environmentally Sustainable Industrial Production. *Grassroots Journal of Natural Resources*, 7(3): s191-s211. Doi: https://doi.org/10.33002/nr2581.6853.0703ukr10

Received: 23 October 2024
Reviewed: 08 November 2024
Provisionally Accepted: 12 November 2024
Revised: 22 November 2024
Finally Accepted: 25 November 2024
Published: 31 December 2024
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Abstract

In the last decade, the circular economy has transformed into a new paradigm that attempts to tackle global environmental and resource challenges. Starting in the late 20th century, this concept began as a reaction to the growing realization of the limits of linear economic systems, focused on the extraction and abandonment of resources rather than sustainability. Technological progress, policy reforms, and heightened environmental consciousness have led over the years, to the adoption of circular principles in industrial processes. Initial efforts were oriented towards waste management and recycling, these being developed to comprehensive approaches that encompass such initiatives as product design, resource regeneration and systemic innovation. The study examines the factors that enhance the application of circular economy in environmentally sustainable industrial production and resource efficiency and environmental damage. Applying circular approaches in the Netherlands leads to a 30% decrease in the demanded primary resources and a 25% decrease in industrial waste. On the same note, the circular economy models have been used in China to reduce CO_2 emissions in heavy industries by 20%. Currently, Japan has managed to recycle 80% of its plastic waste and Germany has applied regenerative technologies into construction to reduce the usage of natural resources by 35%. Nevertheless, the following challenges are evident: high implementation costs, weak legislation and regulatory frameworks, and insufficient waste disposal facilities. The findings of this research will enable partnership support in overcoming these challenges in the promotion of a circular economy as a viable model for industrial transformation.

Keywords

Circular economy; Environmentally sustainable development; Industrial production; Environmental sustainability; Renewable resources

Introduction

The transformative model of environmentally sound industrial development is the circular economy, optimal use of resources and minimization of waste. While such economic systems differ from traditional linear economic systems possessing an emphasis on resource extraction and disposal, circular models rather support resource regeneration and reuse, as highlighted by Ghisellini, Cialani and Ulgiati (2016). This approach especially becomes important given the growing issues of environmental degradation and resource scarcity worldwide and in Ukraine, where industrial sectors are undergoing growing pressure to adopt sustainability. Though recognized, the use of circular principles in Ukraine is nascent, lacking essential implementation, and regulatory support.

However, previous research points to the enabling nature of cutting-edge technologies, like automation and artificial intelligence, for improving resource efficiency (Kirchherr, Reike and Hekkert, 2017; Falkman, 2024). Processes such as product lifecycle management, waste recycling and material sorting are improved using these technologies, reducing dependency on primary resources (Geissdoerfer et al, 2017; Stahel, 2016). But both these advancements have been applied in less than adequate ways in Ukraine, because of a lack of investment in research and development, and a lack of appropriate infrastructure plus fragmented policy frameworks. Although facilities in Ukraine have advanced in waste management and recycling, in energy-intensive industries—steel and construction in particular — Ukraine has not yet integrated fully into the circular economy process.

Studies have shown that the circular economy plays a global role in delivering environmental and economic benefits. Particularly, European Union programs have targeted circular activities and have been successful in lowering primary resource consumption and Co_2 emissions in the main industries (European Commission, 2019; World Economic Forum, 2023). As in the Netherlands and Sweden, also countries have managed to develop models of a circular economy linking advanced technologies and organizational innovations (Circle Economy, 2023). On the other hand, Ukraine's industrial production remains linear, preventing the country from growing in a sustainable, planetary-oriented fashion.

In addition, recent studies argue that circular models have the inherent potential to stimulate social and economic benefits, including job creation and improved productiveness (European Investment Bank, 2023). This is, however, lacking research to explore the local economic benefits of circular practices in Ukraine, including whether such models can be scaled for different sectors of the industry. The gap emphasized the need to explore how circular strategies can be integrated into Ukraine's specific economics, environment and regulatory situation.

The definition of circular economy (CE) is the new development model to increase resource availability and mitigate risks for the environment. The linear process of making a product, using it and in the end throwing it away has caused much devastation to the environment. At present, over 90% of the raw materials mined annually are distributed as waste materials that cannot find their way back into the production loop

hence worsening the negative impacts on the natural environment and fast depletion of resources. The construction industry in particular and automobiles in general are some of the biggest consumers of raw materials and are also the biggest polluters of the environment due to their command of an uninformed production line model. This Perspective shows that the world must transition to the use of circular economy models in which recycling, reuse, and component longevity replace linear business models that rely on virgin resources and produce significant amounts of waste.

Interestingly, there is no lack of work to demonstrate how circular activities can be sustainable. One such example of a circular economy in the Netherlands is helping save 30 per cent of primary resource use and 25 per cent of industrial waste (World Economic Forum, 2023). Similar circular economy models for China have enabled a 20% cut of CO_2 emissions in heavy industries (Yang *et al.*, 2023). Within this context, PCM and waste recycling are not only effective but also require replacements for the conventional linear economy (Geissdoerfer *et al.*, 2017; Kirchherr, Reike and Hekkert, 2017). The circular economy serves as a means by which we studied how its potential to improve the efficiency of resource utilization in industrial production could help make that sort of industrial production less vulnerable to environmental degradation.

This study aims to fill these gaps by assessing whether the circular economy models can increase resource efficiency in Ukraine's industrial production without degrading the environment. This research introduces insights from global successful practices together with local challenges to offer actionable recommendations for scaling up the sustainable industrial transformation in Ukraine. Such findings are especially well-timed for the country at a time when it must navigate the intersection of economic recovery and ecological sustainability.

Methodology

Considering that the previous research had used only quantitative methods to evaluate the impact of circular economy models on industrial production, this research employed the mixed method to assess the impact of the circular economy models on industrial production. Data for the analysis were collected from peer-reviewed articles, annual reports, and indexing databases like Scopus, Web of Science and PubMed using publications from 2015 to 2023. The sources used in this study were based on the European Investment Bank Reports (EIB), Global Competitiveness Index and Circular Economy Report, which are all cited appropriately throughout this study.

Quantitative Analysis

Using multiple regression techniques, the quantitative data analysis quantified the relationship between circular economy practices and key performance indicators including resource efficiency and waste minimization. Precise measurements of the effect of these practices on different industrial sectors were possible, by the use of SPSS software. Variables, such as sector-specific values of waste generation, resource

utilization and production outputs were accounted for in regression models and used as a means of obtaining insights into circular economy models efficiency.

Qualitative Analysis

To perform qualitative analysis, content analysis was used based on coding frequencies to identify themes and patterns in descriptive data spanning leading enterprises. The approach explored commonalities in implementation challenges, innovation contribution and stakeholder views on the practice of circular economy. The coding process was performed to ensure validity and reliability with intercoder reliability checks above 0.8 (a Cohen's Kappa score meaning high agreement between coders). As a result of this comprehensive analysis, a nuanced understanding of how circular economy principles are used in different industrial environments was achieved.

Validation Techniques

The triangulation method was used to ensure the robustness of the finding. The credibility of the conclusions was cross-verified with data from multiple sources such as industrial case studies, statistical reports and who could know better than industrialists themselves. This was the case for the acquisition of qualitative data as well, which underwent iterative analysis cycles to ensure that all insights drawn were both consistent and comprehensive.

This study integrates these methodologies to deliver a comprehensive assessment of circular economy practices, as well as their applicability to promoting sustainable industrial production.

Principles of the Circular Economy and Impacts on Industrial Production

A fundamental understanding of the circular economy (CE) principles is needed for enabling environmentally sustainable industrial development. In contrast to the linear economic model based on resource extraction, product production, consumption and disposal, a CE is a closed-loop system where resources are reused and recycled to achieve zero waste and the least environmental footprint (Kirchherr, Reike and Hekkert, 2017). These ecological and economic challenges are driven by a shift that seeks to address the depletion of raw materials and the increase in industrial waste (Ghisellini, Cialani and Ulgiati, 2016). The relevancy for Ukraine is of course particular given its dependent industries with the highest resource-intensive ones including steel and even more, growing problems of waste management (Kotyrlo *et al.*, 2023). In addition, the move toward CE models would enable Ukraine to follow the European Union legislation on reduction of waste and resource efficiency is bound to increase its industrial competitiveness and environmental sustainability (European Commission, 2019).

1. Closed material cycles. This principle means that all the materials and resources utilised in production should be taken back to the production line as far as possible to reduce the use of new materials. This implies that many products are developed to promote easy disassembly, recycling, and reuse when they are finished with them (Kirchherr, Reike and Hekkert, 2017). For instance, in the electronics manufacturing

area, there are currently measures known as modular, where individual parts may be changed or altered but not the whole product. Closed loops help managers and other stakeholders minimise production costs since the process will likely involve using materials that have been used before. In cases where the materials are new, they are not necessarily expensive or complicated to come by. Besides, it mitigates preservable negative environmental impacts, pollution, and wastage (Geissdoerfer *et al*., 2017).

2. Focus on regeneration and recycling. The principle of this pillar suggests the highest level of material recovery and recycling after their first usage (Ghisellini, Cialani and Ulgiati, 2016). For instance, concrete structures must be recycled in the construction industry to develop materials and waste raw materials to make products. Environmental dispersion cost in product manufacturing is also controlled through recycling and resource recovery to avoid extra disposal costs. It also increases the potential for further advancements in developing new technologies and employment in recycling sectors (European Commission, 2019).

3. Extend the life cycle of products. This principle is about improving our ability to use products for more than one life by focusing on design, which enables repair, upgrade or modernisation of products to give them a longer life instead of having to dispose of them (Stahel, 2016). For instance, instead of discarding automobiles to be replaced by new ones, it is possible to design autos that can be altered or fixed as conveniently as possible. Economies of scale are another benefit of lengthening the product life cycle because it reduces demand for new products with their respective resources, thus slightly decreasing production costs and environmental effects. Industrial enterprises can also develop some service extensions for the repairing or refurbishing service of the product (Kotyrlo *et al*., 2023).

4. The system of renting or sharing products. This principle reverses an item of property with a rental model or use by several people (Kirchherr, Reike and Hekkert, 2017). For instance, some organisations enter into leases of computers, television sets, or any other home-use appliances, and the customer can return the machines to the company after the lease period to be reused or disposed of. The lease model, therefore, preserves the ownership right of companies on products to enhance better control of their life cycle and reuse of resources. It also opens up possibilities for new environmentally sustainable business strategies involving non-one-time selling (World Economic Forum, 2023).

The impact of the circular economy on environmentally sustainable industrial development is shown in figure 1.

The principles of the circular economy significantly positively impact the industry's environmentally sustainable development through more efficient resource use, reduced environmental impact, and stimulation of innovation. These principles open new opportunities to increase enterprises' competitiveness, promote socio-economic development, and improve environmental conditions.

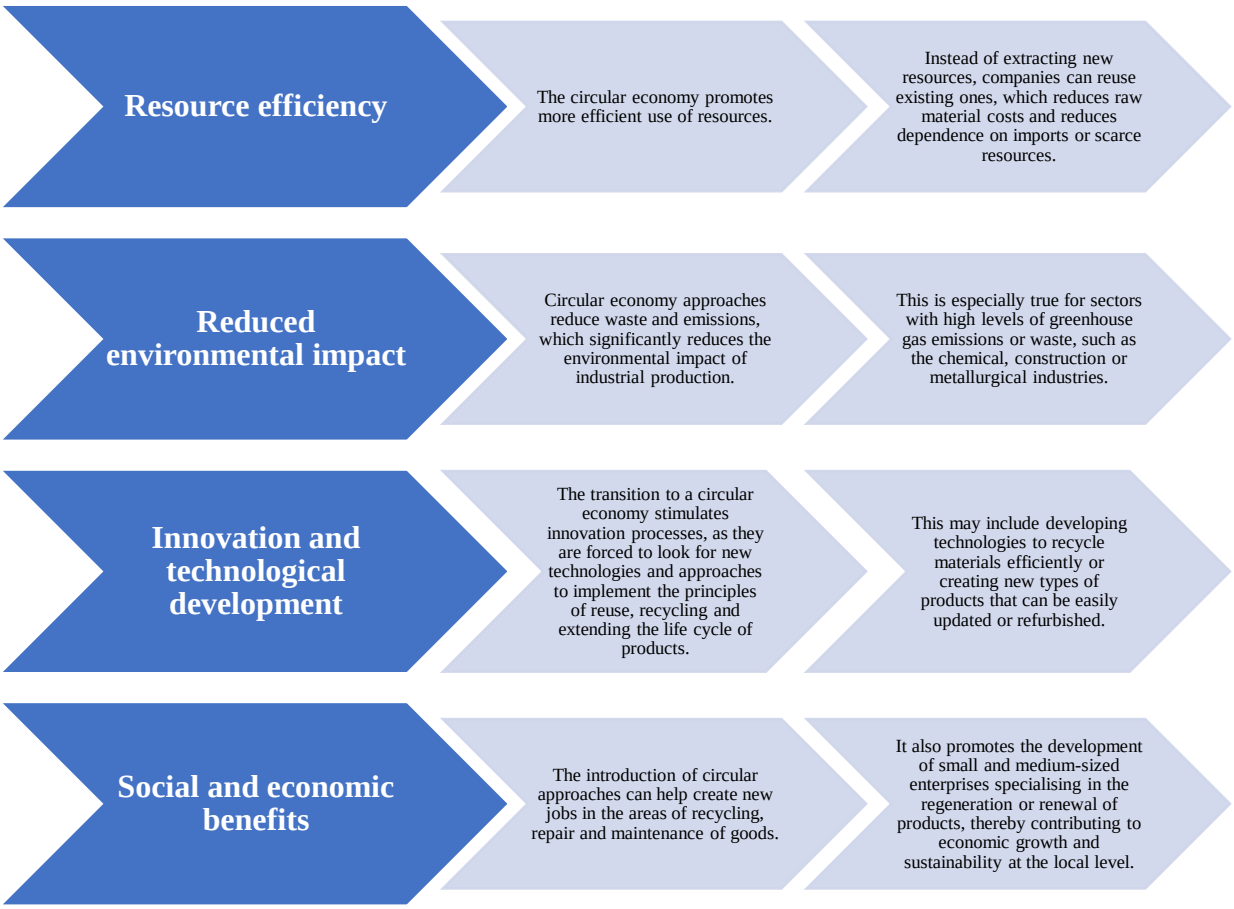
Resource efficiency
The circular economy promotes more efficient use of resources.
Instead of extracting new resources, companies can reuse existing ones, which reduces raw material costs and reduces dependence on imports or scarce resources.
Reduced environmental impact
Circular economy approaches reduce waste and emissions, which significantly reduces the environmental impact of industrial production.
This is especially true for sectors with high levels of greenhouse gas emissions or waste, such as the chemical, construction or metallurgical industries.
Innovation and technological development
The transition to a circular economy stimulates innovation processes, as they are forced to look for new technologies and approaches to implement the principles of reuse, recycling and extending the life cycle of products.
This may include developing technologies to recycle materials efficiently or creating new types of products that can be easily updated or refurbished.
Social and economic benefits
The introduction of circular approaches can help create new jobs in the areas of recycling, repair and maintenance of goods.
It also promotes the development of small and medium-sized enterprises specialising in the regeneration or renewal of products, thereby contributing to economic growth and sustainability at the local level.

Figure 1: Impact of the circular economy on environmentally sustainable industrial development [*Sources:* Ghisellini, Cialani and Ulgiati (2016); Kirchherr, Reike and Hekkert (2017); Stahel (2016); European Commission (2019)]

Best Practices of Circular Economy in Global Manufacturing Sectors

Table 1 below provides examples of successful practices of implementing a circular economy in different manufacturing sectors worldwide. This table demonstrates how different countries have successfully applied circular economy principles in manufacturing sectors to increase resource efficiency, reduce waste, and reduce negative environmental impact.

The development of the circular economy in the context of environmentally sustainable industrial production offers excellent prospects but is accompanied by several challenges. Let's examine the dynamics of the circular economy.

Table 1: Examples of successful practices of circular economy implementation in manufacturing sectors of different countries

Country	*Manufacturing sector*	*Practical implementation of the circular economy*	*Results and Impact*
Netherlands	Electronics manufacturing	Philips Circular Lighting: The company has switched to a rental model for lighting systems, allowing customers to use lighting fixtures without buying them.	Extending product life cycles involves reducing electronics waste, increasing resource efficiency, and reducing the production of new lighting products.
Finland	Pulp and paper sector	UPM Biofore: Processing of forestry waste to produce biofuels and biomaterials. Utilisation of wood by-products for energy generation.	Reducing CO_2 emissions: Optimising the use of forestry waste, reducing dependence on fossil fuels, and reducing energy costs.
Sweden	Furniture production	IKEA: The company has created a take-back programme for old furniture, which can be recycled or reused. Customers can return used furniture in exchange for discounts.	Reducing waste: Raising consumer awareness of furniture reuse, reducing the production of new furniture, and minimising waste.
Germany	Automotive industry	BMW: To produce electric vehicles, recycled and secondary raw materials are used. Modular design is implemented to extend the life cycle of components.	Reducing the use of new materials: Optimising production, improving energy efficiency, reducing negative environmental impact.
Japan	Electronics and household appliances	Panasonic Eco Technology Centre (PETEC): This recycling centre for old household appliances, where refrigerators, televisions, and other appliances are recycled to reuse materials.	Maximising recycling: High metal and plastic recycling level, waste reduction, and resource savings.
France	Fashion and textiles	Patagonia: Worn Wear programme encourages consumers to repair and reuse clothing. The	Raising environmental awareness: Reducing textile waste, encouraging the reuse

Country	*Manufacturing sector*	*Practical implementation of the circular economy*	*Results and Impact*
		company accepts used items for repair or resale.	of goods, and reducing the production of new garments.
Italy	Construction	Italcementi: Using industrial waste such as slag and ash to produce environmentally friendly cement.	Reducing the consumption of natural resources: Optimising waste management, reducing CO_2 emissions, and reducing the use of energy-intensive resources.

Source: European Commission (2019), Ghisellini, Cialani and Ulgiati (2016), Kirchherr, Reike and Hekkert (2017), Stahel (2016)

The level of circularity. According to the Circularity Gap Report (2023)**,** only 7.2% of the global economy operates within a circular model, reflecting a decline from 9.1% in 2018 (Circle Economy, 2023). This means over 90% of the materials extracted annually are wasted or unused for reuse. However, implementing circular solutions can reduce the use of materials by one-third, which is a significant step towards achieving climate goals (World Economic Forum, 2023).

Reducing CO_2 emissions. Using circular approaches in production can reduce CO_2 emissions by 45% by 2030 and achieve carbon neutrality by 2050. This is especially true for construction, steel and aluminium production industries, where material recycling significantly impacts environmental performance (Yang *et al.*, 2023).

Investments. The European Investment Bank has allocated more than €3.4 billion for circular economy-related projects in 2018-2022. The primary investment areas are the industrial, bioeconomic, waste and water management sectors (European Investment Bank, 2023).

Jobs. According to the International Labour Organization, the transition to a circular economy could create 7 to 8 million new jobs worldwide by 2030. These new jobs will come from increased product recycling, repair, and reuse (European Investment Bank, 2023).

Table 2 summarises the development of the circular economy and shows its leading indicators based on the latest research and data.

Countries leading the way in implementing the circular economy are demonstrating active policy and innovation initiatives to improve resource efficiency and reduce waste and emissions. For instance, instead of an abstract goal, the Netherlands has adopted a National Strategy for the Circular Economy (Circular Economy, 2050), which sets the ultimate goal of moving to a 100% circular economy by 2050. The medium-term goal is to reach 50% circularity by 2030. The strategy includes specific legislative initiatives,

such as the Waste Management Law (2017), which regulates the reduction of the use of primary resources (Circle Economy, 2023). *China* introduced the circular economy concept in 2006, including it in the 11th Five-Year Plan for Social and Economic Development. A further impetus came from China's Circular Economy Promotion Law (2008), which actively encouraged investment in renewable resources and innovative practices, especially in industrial sectors (Circle Economy, 2023). Japan has been using the Basic Recycling Law since 2000. The law is entirely aimed at recycling plastic waste in the country. Japan has also adopted the Plastic Waste Circular Economy Strategy of 2019, whose primary goal is to minimise the effects of waste in the country (Circle Economy, 2023). The UK has a National Circular Economy Strategy that was adopted until 2025. It encompasses distinct concepts on recycling such resources, and an excellent record of this would be noted in the Circular Economy – Future Possibilities Index (2024). Sweden and Germany have laws for the circular economy. For instance, Germany has adopted the Resource Management Act (2012), in which circular economy principles are given special consideration, especially in construction and manufacturing, by Construcía (2023).

Table 2: Key indicators of circular economy development in the world by years

Year	*Country*	*Main indicators*	*The main goal of developing a circular economy*	*Development and implementation concept (developed or approved by countries)*
2025	European Union	Reduced use of primary resources by 20%, recycled 60% of household waste	Improving resource efficiency and reducing environmental impact	According to the EU Circular Strategy 2020, developed by the European Commission and approved by the EU countries
2030	Netherlands	Achieve 50% circular economy	Become a 100% circular economy by 2050	According to Circular Economy 2050, developed and approved by the Dutch government
2028	China	Reduced industrial emissions by 25%, recycled 70% of industrial waste	Improving resource efficiency in the industry	The Circular Economy Law of 2008, approved by the Chinese government
2030	Japan	Recycling 80% of plastic waste	Reduce plastic waste generation by 50% by 2050	According to the Plastic Waste Circulation Strategy 2019 developed by the Japanese government
2025	United Kingdom	Recycling 65% of industrial waste	Creating a circular industrial system	According to the National, Circular Economy Strategy developed and approved by the UK government.
2030	Germany	Reduced consumption of natural resources by 30%	Optimising the use of resources in the construction industry	The Resource Management Act 2012, approved by the German government

Source: World Economic Forum (2023), Yang *et al.* (2023), European Investment Bank (2023)

Impact of Circular Models on Enhancing the Efficacy of Resource Utilization in Industrial Production

Countries can prove their leadership through established national approaches, innovative technologies, and investments in circular technologies for environmentally sustainable economic development. Analysing the impact of circular economy models on resource efficiency in industrial production: Table 3 evaluates the effects of circular Economy models on the resource efficiency of production systems. This table shows how circular economy models improve resource efficiency in industrial production through cost differentiation, product life extension, waste minimisation, and renewable energy sources.

Table 3: Impact of circular models on improving the efficiency of resource use in industrial production

Circular model	*Model description*	*Impact on resource efficiency*	*Examples of applications in industrial production*
Recycling and regeneration of materials	This model uses recycled materials to produce new products instead of extracting new resources.	Reduced consumption of primary resources: Recycling allows us to use existing materials, reducing the need to extract new ones, which saves resources and reduces the environmental burden. Increased energy efficiency: Recycling materials (especially metals and plastics) often requires less energy than producing new ones from raw materials.	Metallurgical industry: The use of recycled metals to make new products. Plastics industry: Recycling plastic to make new products.
Designing for an extended life cycle	This model involves designing products to be easily repaired, upgraded or updated.	Reduced costs for new resources: Minimising the rate at which consumers replace products means fewer materials are needed in their construction. Reduced waste: Products that can be repaired or upgraded do not become waste as quickly as such products.	Electronics: Modular design that allows for easy replacement or upgrade of components. Automotive: Technologies enabling cars to be refurbished rather than completely replaced.

Circular model	*Model description*	*Impact on resource efficiency*	*Examples of applications in industrial production*
Shared use or lease model	This model involves renting or sharing products instead of traditional ownership.	Optimising the use of resources: By sharing, one product is used by more consumers instead of many similar products produced from the standard shared material. Reducing the need to produce new goods: Renting and sharing reduces the general production volume of units within a given period.	Rental of equipment and tools: People can hire equipment for various construction projects. Car sharing: Car sharing is an alternative to personal transport.
Cascading use of resources	This model involves the multi-stage use of resources in various production processes before they become waste.	Maximising the efficiency of material use: The same resources can be used at different stages of production for different purposes, extending their proper life cycle. Reducing waste: Materials are used until their value is thoroughly exhausted.	Woodworking industry: The remaining wood is employed to make furniture, and the waste is utilised to produce biomass or energy. Food industry: By-products (e.g., husks or skins) are used in secondary processes such as feed production.
Transition to renewable resources	Use of energy from renewable sources instead of fossil fuels in production processes.	Reducing the carbon footprint: Accessing renewable energy sources has been shown to reduce greenhouse gas emissions for environmentally sustainable development. Reduced energy costs: Finally, many forms of renewable energy, such as the sun or wind, can become cheaper than conventional energy over time.	Electronics production: Using solar energy to power production lines. Automotive industry: Transition to using biofuels or electricity in production processes.

Circular model	*Model description*	*Impact on resource efficiency*	*Examples of applications in industrial production*
Innovative technologies for automated processing	Implementation of automated systems for waste collection and recycling.	Increased accuracy and processing speed: Automation expedites the sorting and processing of the material, making it cheaper to process. Optimising the use of resources: Technologies help reduce resource losses during processing.	Waste processing plants: Automated waste sorting and recycling lines. Textile industry: Technologies for automatically sorting fabrics for reuse or recycling.

Source: Geissdoerfer *et al.* (2017), Ghisellini, Cialani and Ulgiati (2016), Kirchherr, Reike and Hekkert (2017), Stahel (2016)

Innovation as a Key Driver in Implementing the Circular Economy in Industrial Sectors

In industrial sectors, the role of innovation is key for advancing the circular economy as emerging technologies, innovative processes, and new business models enable the practical implementation of the main principles of the circular economy, including closed material cycles, resource recovery as well as the extension of product life cycles (Ghisellini, Cialani and Ulgiati, 2016; Kirchherr, Reike and Hekkert, 2017). These innovations find solutions to these critical industry issues by moving from a linear to a circular economy mindset, increasing resource efficiency by reducing waste and minimizing environmental pollution (Circle Economy, 2023; Stahel, 2016). Below are some key areas that are key to bringing innovation into play when implementing circular economy strategies.

1. Innovative materials and recycling technologies. The reverse nature of the circular economy is one of the most essential criteria for reusing and recycling materials. New products, designed with the circular model, are less environmentally degradable and more accessible to recycle than the previous materials. For instance, biopolymers derived from renewable sources are experiencing steady advances in replacing conventional plastic products and controlling waste (Ghisellini, Cialani and Ulgiati, 2016). Fourthly, the exploitation of advanced recycling processes, including chemical recycling, makes polymers depolymerised to their molecular structures and then recycled to produce materials. All these innovations are ways of achieving closed material loops, using and minimising the requirement of new materials, and at the same time, they also contribute to mitigating environmental pollution (Kirchherr, Reike and Hekkert, 2017).

2. Digital technologies and automation. Technological elements like IoT, AI, and big data are critical for enhancing resource utilisation efficiency (Circle Economy, 2023). For instance, companies can monitor production lines through sensors and the IoT, help

managers detect issues, improve efficiency, and reduce losses (Stahel, 2016). AI is also applied to digest the most effective ways of sorting and recycling waste to increase efficiency in using the available resources in the market. Technological advancement gives firms better control over resource utilisation because they can lessen leakages (TOMRA, 2023).

According to this, Artificial Intelligence (AI) and the Internet of Things (IoT) are pivotal technologies for supporting recycling in the framework of the circular economy. These speed up sorting, monitoring, and processing leading to lower material waste and higher recycling yields (Circle Economy, 2023; Falkman, 2024). For example, TOMRA, the global leader in sensor-based solutions, uses AI-powered optical sensors to sort recyclable materials with very high precision. It enables its technology to differentiate between plastics, metals and glass and direct every material reliably to the right recycling channel, preventing contamination and optimising the quality of recycled materials for manufacturing use (TOMRA, 2023). In addition, IBM's AI and IoT-enabled platform 'IBM Plastic Bank' addresses the problem of plastic waste from the coast to the ocean. Combining block technology, IoT sensors and machine learning algorithms, this idea seeks to encourage local communities to collect plastic waste, and yet send it to IoT-managed recycling centres, for some coins. AI helps to monitor exactly where all the plastic and its chain of supply is, so we know when, if any leakage happens, where that's going to take place (IBM, 2023). Veolia Environnement also embeds IoT sensors in waste management systems to measure the fill-up of waste containers and recyclable bins. By tripling this data with AI algorithms, we optimize collection routes to minimize fuel consumption and emissions. Besides, IoT sensors' data collected by Veolia help forecast sustainable waste recycling and management strategies (Veolia, 2023).

3. Innovative business models. We need the adoption of innovative management approaches to transition to a circular economy. Another well-known example of this is the Product as a Service (PaaS), where companies supply access to a product's utility instead of selling the product itself. Moreover, it extends the product lifespan by providing manufacturer's upgrades and maintenance (Kirchherr, Reike and Hekkert, 2017), minimizing resource use (Among the model). Businesses in the electronics and machinery sectors are beginning to explore PaaS approaches in Ukraine in fields such as industrial equipment and home appliances, providing clients with the option to rent or hire rather than buy. The sharing economy is another emerging model in Ukraine that is represented by platforms aimed at the sharing of tools, vehicles and even office space. Circular economy principles (Kotyrlo *et al.*, 2023) are demonstrated by these initiatives in their reduced demand for new goods and encouragement of resource-efficient practices.

4. Innovations in product design. Designing long-lived products is key to the circular economy as it means that components can be taken apart, upgraded or repaired rather than wasted. These architectural innovations reduce waste and maximize resource use (Ghisellini, Cialani and Ulgiati, 2016). However, such modular designs have previously been adopted by several tech start-ups in Ukraine to replace electronic device components without getting rid of the whole product. Also, manufacturers of furniture have started incorporating designs that encourage easy repair and reuse of materials from European reference practices (Stahel, 2016). Such strategies lead to reducing waste,

reducing production costs, and increasing usability of products from cradle to grave and therefore are particularly appropriate for resource-intensive industries of Ukraine.

5. Development of closed supply chains. Advances in supply chain technologies discussed earlier enable the creation of Closed-Loop Supply Chains that provide for product utilisation and then return products to the supply cycle for recycling. These chains decrease the demand for new material, minimising waste. Only innovative product traceability technologies can generate such supply chains since it would be challenging to identify their origin, constituents, and recyclability. Finalising the supply chains means reducing resource consumption and recycling initiatives in industries. They also discovered that innovation is vital for transitioning towards a circular economy within the industrial sector, which uses resources better, improves environmental performance, and generates new economic development prospects (Ghisellini, Cialani and Ulgiati, 2016; Kirchherr, Reike &and Hekkert, 2017). Technological progress in materials science, information technology, management, product design, and logistics support the development of a green and less costly manufacturing system.

Under the circular economy concept, there is a great potential for industrial development in Ukraine, which may greatly decrease resource wastage and environmental damage. For instance, implementing circular strategies within sectors like cement, aluminium and plastics could prevent up to 45 per cent of greenhouse gas emissions in 2050, the equivalent of removing all the pollution from all the cars in the world today (European Investment Bank, 2023). Such strategies are especially relevant in Ukraine, where its cement and steel industries are the largest emitters and resource exploiters in the region (Kotyrlo *et al.*, 2023).

In addition, if artificial intelligence advancements continue to advance recycling efficiency and predict repair and refurbishment needs to extend product lives and minimize waste (Falkman, 2024). These inventions will bring big changes to Ukraine's already inefficient and low recycling rates of waste management systems. The localization of production is another promising approach that can improve local economic independence and expand supply chains, essential for Ukraine’s recovery and long-term sustainable development amid existing circumstances (World Economic Forum, 2023).

Adopting these strategies would enable Ukraine to join the global trends for industrial competitiveness and reduce its environmental footprint.

However, there are some barriers to applying a circular economy business style. One of the main ones is the regulatory constraints on material recycling and reuse since legislation defines materials as ‘waste’ (World Economic Forum, 2023). Furthermore, it identified that the initial cost of setting up recycling infrastructure and transitioning to low-waste models of producing and consuming goods are relatively substantial and that shifting business models such as product-as-a-service are expensive to realise (Falkman, 2024). Lastly, cultural factors and consumers’ mistrust due to the low quality of remanufactured products continue to be significant challenges for the growth of the circular goods market (International Society for Industrial Ecology, 2023).

The outcome of this work shows that the definition of circular models in industrial production can enhance resource utilisation and minimise environmental harm. According to the present research outcomes, it is possible to note their similarity with other authors, such as Ghisellini, Cialani and Ulgiati (2016) and Kirchherr, Reike and Hekkert (2017), who investigated the significance of circular business models in decreasing waste and reuse of material. However, unlike these authors, the circular economy in industrial processes needs more digitalisation innovation, including artificial intelligence and the Internet of Things, which can enhance waste processing and monitoring (Stahel, 2016; World Economic Forum, 2023).

Geissdoerfer *et al.* (2017) also classify the barriers; the major challenge in implementing circular models is the high initial investment necessary for developing new infrastructures for processing and implementing new business models. These findings for our research show that financial aspects are among the most significant concerns if businesses adopt a circular economy. However, long-term benefits like money saved for future use and less money spent on raw materials will cover the costs, which research done by the European Investment Bank (2023) has shown. Citizens may have some truth with this commendation even though the circular economy is highly accepted in academia, with few critics like Falkman (2024) questioning its efficiency, particularly in energy-intensive industries, including steel and aluminium. The analysis of the mentioned industries lets us state that circular strategies such as recycling and reuse can decrease CO_2 emissions. However, lifting new technologies and governmental support for innovations are necessary to achieve maximum effect (Kotyrlo *et al.*, 2023).

Investments in the circular economy are stymied by obstacles in waste management and regulation and a shortage of local expertise for performing thorough economic analysis. Even today, in Ukraine, and many regions around the world, some materials deemed hazardous waste can still be recycled (classified as such under contemporary regulations). One example is the many industrial by-products listed in the hazardous waste category by the European Union Waste Framework Directive (Directive 2008/98/EC) which, through strait laced handling and disposal requirements, reduce recycling rates to extremes (European Commission, 2019). Likewise, the Resource Conservation and Recovery Act in the USA categorizes some secondary materials flowing in from industrial processes as hazardous and barriers for companies aiming to utilize these materials in circular production (Kotyrlo *et al.*, 2023).

Waste classification and management practices present similar problems in Ukraine. A lack of a clear distinction between recyclable and non-recyclable waste does not allow the country to optimise its material recovery. Poor waste infrastructure, as well as weak enforcement of environmental regulations, also prevent progress to a circular economy. Japan already has a Basic Act on Establishing a Sound Material Cycle Society, which allows the recycling of “Specially Controlled Waste” under certain conditions (Stahel, 2016).

There are also regulatory barriers, both in the sense that recycled materials are not universally accepted within an industry and in the fact there are no standards for recycled material at all. For instance, the German Circular Economy Act defines the quality and safety of recycled products for manufacturers and consumers (Ghisellini, Cialani and

Ulgiati, 2016). Perhaps such standards should also be adopted by Ukraine, particularly in the construction and metallurgy sectors, as these industries are essential for recycled materials use to reduce raw material consumption and environmental impact (Kirchherr, Reike and Hekkert, 2017).

Another important area for regulatory improvement is to incentivize circular practices. Tax exemptions and subsidies for businesses that participate in circular economy activities could favour the transition from a linear to a circular model. For example, the European Investment Bank provides a Circular Economy Incentive Program wherein companies can compensate for the costs of a circular venture with government support (European Investment Bank, 2023). However, introducing similar incentives in Ukraine has the potential to overcome the financial and logistical barriers and make local industries more accessible to circular models.

In prior literature, cultural and regulatory factors that can impede the circular economy implementation have not been consistently emphasised. For instance, some authors (Kirchherr, Reike and Hekkert, 2017) identify legislation constraints that do not always encourage the reuse of products since certain types of waste are labelled “hazardous”. The solution to this problem is reforms in the legal framework and increased cooperation between industrial corporations and the authorities. The results thus confirm the hypothesis that the circular economy advances environmentally sustainable industrial development by improving resource productivity and mitigating environmental impacts on industrial sectors. However, new investigations and concrete applications of such techniques, such as automation of processing and utilisation of renewable energy sources, are still required to realise the full benefits of circular models (Stahel, 2016).

The drawbacks of our work include the incomprehensive character of available data on the actual economic effects of applying a circular economy at various stages of production processes. Subsequent research should be dedicated to a deeper study of how the CE influences the long-term economic implications and industry differentiation.

Recommendations

Put in place Tax Incentives for Circular Practices. The government must adopt tax relief schemes for organizations operating a circular economy process like recycling, reusing and designing durable products. Subsidies given to businesses in order to use eco materials or run closed-loop practices are examples of such incentives that help overcome the financial hurdle barrier and push for cause from linear to circular ways.

Endorse Government Funded Programs for Recycling Infrastructure. To fill the gap created by the lack of recycling facilities, authorities should give grants or subsidized loans to establish new recycling centres or improve old ones. Material recovery rates will be maximized with this enhanced infrastructure and will support circular economy initiatives.

Quality Standards for Recycled Materials Develop and Enforce. Recycled materials need some clear benchmarks regarding their quality and safety that’s where policymakers and industrial leaders need to collaborate. Introducing recycled products will gain confidence

not only from the manufacturers but also from the consumers, which will increase the adoption of recycled products with internationally recognized standards.

Contribute to the promotion of Research and Innovation in Circular Technologies. Recycling processes, resource recovery and product durability will be improved by encouraging research and development in advanced technologies, like artificial intelligence and IoT. Public and private sector partnerships should foster the support of innovations in waste classification, automation and sustainable product design.

Education and Awareness Programs must be encouraged. Students, professionals as well as the public in general should be targeted by educational initiatives and awareness campaigns, in order to raise awareness of circular economy principles. Lesson learned: Workshops, training sessions and programmes on community engagement can promote the economic and environmental advantages of adopting circular practices, reaching way beyond only a smaller section of the business, the final buyer, or producer.

Actionable steps toward fostering sustainable, long-term adoption of circular economy models, and long-term economic resilience are outlined in these recommendations.

Conclusion

The potential contribution of the circular economy to improved resource productivity, diminished environmental impact and sustainable industrial development is very high. Achieving the full benefits of a circular economy will depend on the coordination efforts between policymakers and industry leaders, points out this study. However, regulatory, financial, and cultural barriers inhibit the great potential for a successful implementation of circular practices. To address these challenges, we need to develop a targeted strategy, for example, incentives, the development of infrastructure and educational initiatives that will establish a framework for a robust transition to a circular economic system, from a linear one. Industries can then focus on innovation, standardization, and awareness, assuring sustainable growth, without a large impact on their ecological footprint. Key recommendations concluded in the study include:

- Tax Incentives for Circular Practices: Provide tax reliefs for organizations engaging in recycling, reuse, and eco-friendly designs. Financial incentives will encourage the adoption of circular approaches.
- Government-Funded Recycling Programs: Establish programs with grants or subsidized credit to build recycling facilities, improving the return and reprocessing of materials.
- Quality Standards for Recycled Materials: Collaborate to ensure high-quality recycled materials meet safety and performance standards, boosting consumer and manufacturer confidence.
- Promote Research and Innovation: Fund research in recycling technology, resource retrieval, and product durability. Encourage AI and IoT advancements in waste management.
- Education and Awareness Programs: Increase understanding of circular economy principles through educational programs, workshops, and campaigns.

These strategies provide a roadmap for policymakers and stakeholders to foster sustainable development and reduce climate impact.

References

Arsawan, I.W.E., Suhartanto, D., Koval, V., Tralo, I., Demenko, V. and Azizah, A. (2024). Enhancing the circular economy business model towards environmentally sustainable business performance: Moderating the role of environmental dynamism. *Journal of Infrastructure, Policy and Development*, 8(5). DOI: https://doi.org/10.24294/jipd.v8i5.3321

Atstaja, D., Koval, V., Grasis, J., Kalina, I., Kryshtal, H. and Mikhno, I. (2022). Sharing model in circular economy towards rational use in environmentally sustainable production. *Energies*, 15(939). DOI: https://doi.org/10.3390/en15030939

Chatziparaskeva, G., Papamichael, I., Voukalli, I., Loizia, P., Sourkouni, G., Argirusis, C. and Zorpas, A.A. (2022). End-of-life of composite materials in the framework of the circular economy. *Microplastics*, 1(3): 377–392. DOI: https://doi.org/10.3390/microplastics1030028

Circle Economy (2023). *Circularity Gap Report 2023*. Circle Economy. Available at: https://www.circularity-gap.world [Accessed on 10 October 2024]

Circle Economy (2023). *Circularity Gap Report 2023.* Available at: https://www.circularity-gap.world [Accessed on 10 October 2024]

Circular Economy – Future Possibilities Index (2024). *Countries leading in the circular economy*. Future Possibilities Index. Available at: https://futurepossibilitiesindex.com/indicators/circular/ [Accessed on 10 October 2024]

Construcía (2023). Which countries are leading the change in the circular economy? Construcía. Available at: https://www.construcia.com [Accessed on 10 October 2024]

Diez-Cañamero, B. and Mendoza, J.M.F (2023). Circular economy performance and carbon footprint of wind turbine blade waste management alternatives. *Waste Management*, 164: 94–105. DOI: https://doi.org/10.1016/j.wasman.2023.03.041

Dotsenko, N.A. and Batsurovska, I.V. (2022). Estimation of efficiency of use of water-lifting equipment in technological processes of agricultural production. *IOP Conference Series: Earth and Environmental Science*, 1049: 012047. DOI: https://doi.org/10.1088/1755-1315/1049/1/012047

European Commission (2019). *Implementation of the Circular Economy Action Plan*. Available at: https://ec.europa.eu/environment/circular-economy/ [Accessed on 10 October 2024]

European Investment Bank (2023). Circular economy overview. *EIB Circular Economy Lending*. Available at: https://www.eib.org/en/publications/the-eib-in-the-circular-economy.htm [Accessed on 10 October 2024]

Falkman, N. (2024). The circular economy – a hub of innovation in AI's quest for commercial value. *Robeco Global*. Available at: https://www.robeco.com/en/insights/2024/02/circular-economy-ai.html [Accessed on 10 October 2024]

Geissdoerfer, M., Savaget, P., Bocken, N.M.P. and Hultink, E.J. (2017). The Circular Economy – A New Sustainability Paradigm? *Journal of Cleaner Production*, 143: 757–768. DOI: https://doi.org/10.1016/j.jclepro.2016.12.048

Ghisellini, P., Cialani, C. and Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114: 11–32. DOI: https://doi.org/10.1016/j.jclepro.2015.09.007

IBM (2023). Plastic Bank: Leveraging AI and IoT for coastal waste management. Available at: https://www.ibm.com [Accessed on 10 October 2024]

International Society for Industrial Ecology (ISIE) (2023). Team of ISIE members releases circular economy report. *International Society for Industrial Ecology*. Available at: https://is4ie.org/whitepaper [Accessed on 10 October 2024]

Kirchherr, J., Reike, D. and Hekkert, M. (2017). Conceptualising the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127: 221–232. DOI: https://doi.org/10.1016/j.resconrec.2017.09.005

Kotyrlo, O., Bratus, H., Marushchak, S., Gorokhova, T. and Prav, Y. (2023). The circular economy model and the imperatives of its implementation in Ukraine. *Economic Affairs*, 68(1s): 213–222. DOI: https://doi.org/10.46852/0424-2513.1s.2023.24

Koval, V., Mikhno, I., Tamosiuniene, R., Kryshtal, H., Kovalenko-Marchenkova, Y. and Gui, H. (2023). Ensuring environmentally sustainable consumption behaviours in circular economy engagement. *Transformations in Business & Economics*, 22(2): 144–160. Available at: http://www.transformations.knf.vu.lt/59/article/ensu [Accessed on 10 October 2024]

Stahel, W.R. (2016). The circular economy. *Nature*, 531(7595): 435–438. DOI: https://doi.org/10.1038/531435a

Sumets, A., Tyrkalo, Y., Popovych, N., Poliakova, J. and Krupin, V. (2022). Modelling of the environmental risk management system of agroholdings considering the environmentally sustainable development values. *Agricultural and Resource Economics: International Scientific E-Journal*, 8(4): 244–265. DOI: https://doi.org/10.51599/are.2022.08.04.11

TOMRA (2023). Sensor-based recycling solutions for a sustainable future. Available at: https://www.tomra.com [Accessed on 10 October 2024]

Veolia (2023). IoT and AI in waste management: Driving efficiency and sustainability. Available at: https://www.veolia.com [Accessed on 10 October 2024]

Vogiantzi, C. and Tserpes, K. (2023). On the definition, assessment, and enhancement of circular economy across various industrial sectors: A literature review and recent findings. *Sustainability*, 15(23): 16532. DOI: https://doi.org/10.3390/su152316532

World Economic Forum (2023). How the circular economy secures manufacturing supply chains. *WEF Circular Economy Insights*. Available at: https://www.weforum.org/agenda/2023/02/circular-economy-manufacturing [Accessed on 10 October 2024]

World Economic Forum (2023). 9 examples of a circular economy accelerating the transition. *World Economic Forum*. Available at: https://www.weforum.org/agenda/2023/03/9-examples-circular-economy-accelerating-transition/ [Accessed on 10 October 2024]

Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A.I., Fawzy, S., Rooney, D.W. and Yap, P.S. (2023). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters*, 21: 55–80. DOI: https://doi.org/10.1007/s10311-022-01499-6.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5
Conceived and designed the research or analysis	Yes	No	Yes	Yes	Yes
Collected the data	Yes	No	Yes	No	Yes
Contributed to data analysis & interpretation	Yes	Yes	No	Yes	No
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	No	Yes	No	Yes	No
Editing of the article/paper	Yes	Yes	Yes	Yes	Yes
Supervision	No	Yes	No	Yes	Yes
Project Administration	Yes	No	No	No	No
Funding Acquisition	No	No	No	No	No
Overall Contribution Proportion (%)	20	20	20	20	20

Funding
No financial support was received for the research and writing of this article.

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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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